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Description

Flat surface loudspeaker, and a method for its operation

The invention relates to a flat surface loudspeaker as claimed in the precharacterizing clause of patent claim 4, and to a method for its operation as claimed in the precharacterizing clause of patent claim 1.

Flat surface loudspeakers of said generic type have been known per se for a long time, for example from German Patent 484 872. An oscillating coil is used in a flat surface loudspeaker, operating on the electro-dynamic principle and being placed directly on a surface - intrinsically initially of any desired size and thickness and composed of a chosen material -, and being mechanically fixed there. When the oscillating coil is stimulated electrically by a sound transmitter, then its oscillations are transmitted to the surface, which acts as a membrane, so that it is itself used as a sound-emitting surface. There will be a large number of potential applications per se for an electroacoustic transducer of this generic type. Apart from a few exceptions, it has nevertheless not been used to any major extent so far owing to its electroacoustic characteristics, in particular its transfer function.

The operation of the sound-emitting surface is primarily governed by its mechanical characteristics. This surface can transmit sounds or tones only by oscillating mechanically. Quite apart from the means by which it is clamped in, that is to say the mechanical mounting and the point at which the oscillating coil is fixed on it, a surface in the form of a plate in which,

preferably, bending oscillations are stimulated is intrinsically a relatively complex structure in terms of its oscillation behavior. Whereas with commercially available loudspeakers based on the electrodynamic principle it is still largely possible, even if actually only by making compromises, to optimize the acoustic characteristics

of the sound-emitting membrane, this is not directly possible with flat surface loudspeakers. This problem can be illustrated by an example: if the glass surface of a shop window on which an oscillating coil is mounted is used as a flat surface loudspeaker, then the material, shape and dimensions of the sound-emitting surface, and the way in which it is clamped in as well, are essentially fixed. In this example, the frequency response of the flat surface loudspeaker is thus essentially predetermined. Typically, the natural resonances of the surface used for sound emission and with this material and the dimensions of the shop window have a frequency response which - in simple terms - can be described by enhanced response in the low frequency area and, furthermore, by a tendency to produce a tinkling noise, which is due to the influence of higher-order natural resonances that are still in the audible range. Corresponding characteristic nonlinearities also occur with other materials, such as wood or synthetic materials.

A flat surface loudspeaker having a built-in sound wall is known from GB 2 265 519 A, which has nonlinearities in transmission owing to the internal air pressure and the magnetic field in the transducer. The nonlinearities are taken into account by means of digital electronic compensation; the loudspeaker contains power amplification. This allows the loudspeaker to be designed to be much thinner than would otherwise be possible. The drive forces are exerted on a major proportion of a membrane in order to avoid modal distortion which occurs in the sound-emitting surface at low and medium frequencies. The loudspeaker is suitable for wall mounting, with minimal projection into the room.

GB 289 185 A discloses an acoustic reproduction appliance, for amplification of the power on an audiosignal, which has been modified by means of a nonrecursive digital filter, and which emits the sound via a loudspeaker. The reproduction appliance has a sound funnel in the form of a horn on the loudspeaker, as well as means for signal processing of the audio signal, comprising a nonrecursive digital filter. An acoustic resistance can be mounted on the opening of the loudspeaker horn. The filter has an inverse characteristic to the transmission characteristic of the loudspeaker horn, including the acoustic resistance. Furthermore, the reproduction appliance may have a linear phase equalizer for modulation of the amplitude characteristic of the audio signal. The digital filter in the signal processing means may be in the form of a digital FIR (Finite Impulse Response) filter.

EP 0 168 078 A1 discloses an arrangement for converting an electrical signal to an acoustic signal or vice versa, which has an electroacoustic transducer and means for reducing the distortion in the output signal from the arrangement. The means are in the form of a nonlinear network which has at least two parallel circuit branches, at least one of which compensates for the second or higher order nonlinear distortion components.

An appliance to compensate for reproduction errors in an electroacoustic transducer, such as a loudspeaker or a microphone, by means of a computer circuit is known from US 4,675,835. The electrical input signals are converted in a digital computer circuit to output signals which have been modified by inherent characteristics

of the transducer, and are stored in a memory by means of a program. The program is stored in the same way. When analogue computer circuits are used, the complex inherent reproduction of the transducer, in terms of the amplitude/frequency transmission and the phase/ frequency transmission, is approximated mathematically in a closed inverse form, and the resulting function is simulated by means of integrated, addition, inversion and adjustment elements.

A method and a system for transmission of audio frequencies in a sound reproduction system are disclosed in EP 0 567 061 A1, which sound reproduction system has at least one loudspeaker mounted in a housing, and in which the frequency transmission of the loudspeaker is equalized by means of a filter. Before feeding in a signal in a broadband one-way loudspeaker, which reproduces frequencies essentially over the entire audible range, with said loudspeaker emitting audio signals, the frequency transmission of the loudspeaker when mounted in its housing is equalized by means of a filter, which is likewise a broadband filter covering the entire audible range. The filter provides an approximated inverse transmission in the desired pass band of the loudspeaker system, which comprises said loudspeaker mounted in its housing, with the inverse transmission being formed on the basis of the measured frequency transmission of the loudspeaker system. If desired, the measured frequency transmission can be averaged in the frequency domain, and the inverse transmission is then formed from the averaged frequency transmission.

As is known, for example, from US-A-3 728 497 as well as US-A-3 636 281 or US-A-3 449 531, efforts have been made to overcome the known disadvantages of a flat surface loudspeaker by means of physical measures. Certain improvements have been possible in this way, but a fundamental solution which would give flat surface loudspeakers a wide range of applications has not yet been obtained from the experiments carried out so far.

The invention is thus based on a first partial object of specifying a means, using a method of the type mentioned initially, using which the nonlinearities in the frequency response of flat surface loudspeakers can at least be coped with to such an extent that their sound spectrum is sufficiently natural for the respective application.

A second partial object is to use such a method to provide a flat surface loudspeaker of the type

mentioned initially, whose electroacoustic characteristics are - depending on the application - optimized such that predetermined requirements in an individual application relating to the quality of sound produced in this way are thus satisfied.

In a method of this generic type for operating a flat surface loudspeaker, the first partial object is achieved by the features described in the characterizing part of patent claim 1.

In a flat surface loudspeaker of the type mentioned initially, the second partial object is achieved by the features described in the characterizing part of patent claim 4.

In the field of electroacoustics, it has long been known in the development of optimized electroacoustic transducers that the effects of the influencing variables which govern the transmission quality of an electroacoustic transducer often counter one another in a contrary manner. A physical/mechanical solution in which all these influencing variables are optimized in the same way is thus impossible, and every electroacoustic transducer is invariably a compromise solution, due to systematic factors. One relevant example of this is the known loudspeaker box, with a number of individual, specifically designed loudspeakers. The solutions to the two partial objects according to the invention are based on the joint idea that such compromises, which are characterized by physical measures, have far less probability of leading to a satisfactory result in a flat surface loudspeaker. A flat surface loudspeaker is actually not composed of individual, specifically designed loud speaker units,

like a loudspeaker box. The development of flat surface loudspeakers so far has shown that solution approaches which attempted to improve flat surface loudspeakers by physical measures did not lead to a satisfactory result.

The invention is a departure from the conventional ideas of electro-acousticians and adopts a different approach. The electroacoustic characteristics of flat surface loudspeakers are governed by the total effect of the characteristics of the oscillating coil or coils used, and by the mechanical characteristics of the sound-emitting surface that is used. The electroacoustic transfer function for each arrangement of a flat surface loudspeaker defined in this way is thus defined in the form of its frequency response - apart from tolerances. If the corresponding frequency curve is determined by measurement, then the frequency response of the flat surface loudspeaker can be compensated for, and hence linearized, by means of a filter device which is arranged in the operating arrangement of the flat surface loudspeaker between the sound source and the amplifier located upstream of the oscillating coil or oscillating coils, provided the transfer function of the filter device is essentially the inverse of the corresponding function for the combination of an oscillating coil or coils and the sound-emitting surface.

According to developments of the invention, the transfer function of the filter device is simulated by means of digital filters, in particular by means of FIR (Finite Impulse Response) filters, whose filter coefficients are derived from the inverse frequency curve of the flat surface loudspeaker.

The filter device preferably has a sample and hold element as the input element, which is connected via an analogue/digital converter to the digital filter, whose output is connected to a digital/analogue converter.

According to another development of the invention, the filter device is equipped with a digital signal processor.

Nowadays, digital signal processors are widely used and, owing to the progress in the development of integrated circuits, are also already available for relatively

computation-intensive "real time" applications. Digital signal processors are freely programmable, even if this is only to a limited extent due to the available volume for the program memory. It is thus possible to match the operation of the digital signal processor to different sound-emitting surface materials, such as wooden materials, glass, plastics, and, inter alia, polyurethane foam. Furthermore, it is also possible to provide sound-emitting surfaces with different shapes. It is thus clear that the invention has, in particular, overcome the greatest obstruction to the widespread use of flat surface loudspeakers in the past. The shape and material selection for the sound-emitting surface are largely unconstrained, without any need to accept any reduction in the sound emission quality. Although very high quality, which is thus still relatively expensive due to complexity reasons, is not required for every application, it is nevertheless feasible to implement embodiments which even completely satisfy hifi (high fidelity) requirements. Volume and weight savings with flat surface loudspeakers compared to commercially available loudspeaker boxes are a major advantage, and not only in these applications.

Further advantages and refinements of the solution according to the invention can be found in the following description of exemplary embodiments.

Exemplary embodiments of the invention will be described in more detail in the following text with reference to the drawing, in which:

Figure 1 shows a flat surface loudspeaker in conjunction with a measurement arrangement for measuring its frequency response,

Figure 2 shows a first embodiment of the circuit arrangement for operating the flat surface loudspeaker, and

Figure 3 shows a further embodiment of the circuit arrangement as shown in Figure 2.

Figure 1 shows, schematically, a flat surface loudspeaker 1 which has a sound-emitting surface 2 in the form of a plate and on which, by way of example, two oscillating coils 3 and 4 are arranged. The oscillating coils 3 and 4 are mechanically fixed on the sound-emitting surface 2 such that, when they are electrically stimulated, the mechanical oscillations which they carry out in this case are transmitted to the sound-emitting surface 2 in order that it is itself caused to oscillate, and hence to emit sound. In a functional operating circuit, the oscillating coils 3, 4 are connected in parallel to the outputs of an amplifier 5 whose input, during normal operation, is coupled to a sound source, which is not shown in Figure 1.

For a person skilled in the art of technical acoustics, it is immediately evident that, inter alia, the characteristics of the sound-emitting surface 2, its shape, the size of its surface area, it thickness and, above all, also its mechanical characteristics together with the configuration of the oscillating coil or coils 3 and 4 as well as their local arrangement on the sound-emitting surface 2 govern the acoustic characteristics of the flat surface loudspeaker 1. Since, for example, completely different materials can be used for the sound-emitting surface 2, this itself results in a difficulty in material selection. This is because this depends on whether the flat surface loudspeaker 1 has a high level of attenuation, on the one hand in particular in the higher frequency range, as in the case of wooden materials, or on the other hand in the low-frequency range as, for example, in the case of glass and plastics so that, in the latter case, high frequency components are reproduced excessively, thus resulting in a tendency to tinkling.

These problems have resulted in flat surface loudspeakers not so far being used in large numbers in intrinsically feasible applications, even though the principles relating to this have been known for a very long time, since other electroacoustic transducers are known whose frequency response can be corrected more easily.

In order to solve this problem, Figure 1 now also shows a measurement arrangement by means of which the transmission characteristics of a flat surface loudspeaker 1 are analyzed acoustically. In order to determine the frequency response of the measurement object, that is to say of a specific type of flat surface loudspeaker 1, a frequency analyzer 6 is provided which emits a defined electrical measurement signal to the amplifier 5 at a predetermined level and at a tunable frequency, and causes the flat surface loudspeaker 1 to emit sound via the oscillating coils 3, 4. A measurement microphone 7, which is connected to the input of the frequency analyzer 6, is arranged at a defined distance from the flat surface loudspeaker 1, preferably along its center axis.

The frequency response of the measurement object is determined using this measurement arrangement, which is preferably set up in an anechoic room, in order to simulate sound propagation in free space as exactly as possible in measurement conditions. As indicated above, this frequency response of a flat surface loudspeaker 1 is governed by object-typical nonlinearities, for which reason it must be measured individually, at least for each object type. This results in an essential measure for the electroacoustic transmission characteristics of a flat surface loudspeaker 1. The inverse function of the frequency curve obtained in this way is formed in order to compensate for the nonlinearities of the frequency response.

Figure 2 uses an operating circuit for the flat surface loudspeaker 1 to illustrate, schematically, how the described measurement result is used in order to correct for the distortion in the transmission

characteristics of a specific electroacoustic transducer. By way of example, the sound source is illustrated in Figure 2 in the form of a magnetic tape recorder 7, whose output is connected to the amplifier 5 for the flat surface loudspeaker 1, via a filter device 8. As is indicated schematically in Figure 2, a transfer function is implemented in the filter device 8 which is essentially the inverse of the characteristic frequency curve

measured for this type of flat surface loudspeaker 1. The profile of the transfer function of the filter device 8 must be approximated more closely to the inverse frequency curve of the flat surface loudspeaker 1 the more stringent the requirements to which the resultant transmission quality of the flat surface loudspeaker 1 is subject in the respective application. In the filter device 8, the electrical sound signals supplied from the magnetic tape recorder 8 are subjected to preemphasis in such a way that this just counteracts the frequency response of the flat surface loudspeaker 1. This sound signal, with preemphasis, is supplied via the amplifier 5 to the oscillating coils 3, 4 of the flat surface loudspeaker 1. The transfer function of the conversion to acoustic signals in the flat surface loudspeaker 1 counteracts this preemphasis once again. The resultant frequency response of the flat surface loudspeaker 1 is better linearized the more accurately the transfer function of the filter device 8 approximates to the inverse frequency curve of the flat surface loudspeaker 1.

As is known, electrical filters can also be formed from discrete elements, but complex transfer functions for a bandpass filter in the audible range, such as those which are used in this field of application in conjunction with flat surface loudspeakers 1, can be provided using discrete components only with great complexity, and then only to a first approximation. Implementations of the filter device 8 using discrete components are therefore suitable in conjunction with a flat surface loudspeaker 1 only when its transmission quality is subject only to restricted requirements in a particular application.

Figure 3 thus shows a further embodiment for the operating circuit of a flat surface loudspeaker 1, by means of which even hifi (high fidelity) requirements can be satisfied. The embodiment shown in Figure 3 differs from the embodiment shown in Figure 2 in the further refinement of the filter device 8. Figure 3 shows the filter device 8 as a digital filter. Its

input circuit, which is connected to the magnetic tape recorder 7 (which is indicated once again as an example of a sound source) is in the form of a sample and hold element 9 - frequently also referred to as a sample and hold circuit. The electrical sound signal supplied as an analogue signal from the magnetic tape recorder 8 is thus sampled using a predetermined sampling theorem, and the respectively sampled instantaneous value is buffer-stored and is supplied to an analogue/digital converter 10 which is connected to it and which converts the successive instantaneous values to digital signals expressed in binary form. The signals are supplied in this form to a digital signal processor 11. On the output side, the digital signal processor 11 is connected to a digital/analogue converter 12, by means of which its binary output signal is converted back to an analogue electrical signal, which is supplied via the amplifier 5 to the flat surface loudspeaker 1.

This refinement of the filter device 8 advantageously makes use of the progress in the development of digital signal processing. Nowadays, the semiconductor industry offers the user powerful signal processors, which are already in widespread use, even for real-time applications. Application options for digital signal processors as well as refinements by means of appropriate programs can therefore be assumed to be known in this case. The circuit design of the digital signal processor is therefore not shown in detail in the schematic illustration in Figure 3. Normally, in addition to a microcontroller, the actual control unit, has a signal processor a program memory, a data memory and an input/output memory, which are connected to one another via a bus system with parallel address, control and data lines. The capability to store a

specific program relating to the respective application in the program memory makes the digital signal processor suitable for an electronic circuit which can be used universally and, in the present field of application, is used to simulate the transfer function of the filter device 8.

It is advantageous in this case for the filter or filters to be in the form of FIR (Finite Impulse Response) filters, by means of which even complex transfer functions for real-time requirements can be provided in a known manner. If the transmission quality of the flat surface loudspeaker is subject to very stringent requirements, such as those for hifi quality, in a specific application, then, owing to the signal processing required in real-time conditions, it may be necessary to carry out this signal processing by parallel operation of a number of signal processors, without in the process needing to depart from the fundamental solution approach.

The embodiments described above open up a wide range of applications for flat surface loudspeakers. The capability to program the digital signal processor 11 freely allows the complexity for the measurement of the frequency response of the respective type of flat surface loudspeaker 1 and the conversion of the measured frequency curve to an inverse transfer function (which is a greater or lesser approximation of this) of the filter device 8 to be optimized for the respective application. Both physically small and large format flat surface loudspeakers can be produced. Since the choice of materials for a flat surface loudspeaker designed according to the invention is no longer to a major extent subject to the conventional restriction, even materials with a very low relative density, for example, can also be chosen for the sound-emitting surface. Particularly in mobile applications, in which transport capabilities invariably play a substantial role, it is a major advantage to move a light flat surface loudspeaker composed of polyurethane foam instead of a heavy, voluminous conventional loud

speaker box. Flat surface loudspeakers according to the invention can thus be used not only for commercial purposes, such as public sound-emission facilities and advertising hoardings, but also as high-quality loudspeaker device in the personal field, which are at the same time very flat and, for example, are integrated in furniture.